Draft Total Maximum Daily Load
of Nutrients and Dissolved Oxygen
in the Christina River Basin,
Pennsylvania, Delaware, and Maryland

I. Introduction

This document will establish the Total Maximum Daily Load (TMDL) of Nutrients and Dissolved Oxygen in the Christina River Basin as determined by the Environmental Protection Agency (EPA), Region III. These TMDLs have been cooperatively developed with the Pennsylvania Department of Environmental Protection (PA DEP), Delaware Department of Natural Resources and Environmental Control (DE DNREC), Maryland Department of the Environment (MDE), and the Delaware River Basin Commission (DRBC). This effort represents the first step of a two-step TMDL process which is designed to acknowledge past and ongoing pollution control efforts in the watershed as well as other technical considerations in evaluating and developing TMDLs.

II. Historical Perspective

In 1991, at the request of DE DNREC and PA DEP, the Commission agreed to mediate water management issues in the "interstate" Christina River Basin. This request followed efforts of the States and EPA to cooperatively manage this system. A host of water resources issues had arisen in the Basin, including interstate and intrastate coordination of monitoring, modeling, and pollution controls; balancing the conflicting demands for potable water while maintaining necessary minimum pass-by requirements to sustain aquatic life; protection of vulnerable, high quality scenic and recreational areas, restoration of wetlands and other critical habitats; and implementation of Exceptional Resource and Environmental Sensitive (ERES) objectives. A comprehensive basin approach was needed. The DRBC facilitated a series of meetings with DE DNREC, PA DEP, EPA, Chester County Water Resources Authority (CCWA) and the United States Geological Survey (USGS). EPA funded a study by SAIC for completion of an initial data assessment and problem identification study for the non-tidal portion of Brandywine Creek. The findings of this study, Preliminary Study of the Brandywine Creek Sub-basin, Final Report, September 30, 1993, provided a framework for use in a multi-step TMDL study for the entire Christina Basin. Agreement was reached in late 1993 to initiate a cooperative and coordinated monitoring and modeling approach to produce TMDLs for low-flow conditions by late 1999. During these discussions on low-flow conditions, it was recognized that efforts would be needed for high-flow/nonpoint source impacts. In 1993, EPA recommended that DRBC expand the effort to consider high flow conditions. As a result, the Christina Basin Water Quality Management Committee (CBWQMC) was created with the purpose of addressing the applicable water quality problems and management policies on a watershed scale. The Committee represents a variety of stakeholders and interested parties including the Brandywine Valley Association/Red Clay Valley Association (BVA/RCVA), Chester County Conservation District (CCCD), Chester County Health Department (CCHD), Chester County Planning Commission (CCPC), CCWA, DE DNREC, Delaware Nature

Society (DNS), DRBC, New Castle County Conservation District (NCCD), PA DEP, EPA-Region III, USGS, United States Natural Resources Conservation Service (USDA-NRCS), and the Water Resources Agency for New Castle County (WRANCC). The Cecil County, Maryland Department of Public Works and MDE were not originally included, however, once it was discovered that the TMDL would impact point sources in Maryland, these organizations were contacted and have participated in the development of the TMDL since that point.

The Committee developed a unified, multi-phased, 5-year Water Quality Management Strategy (WQMS) which would address water quality problems and sources through 2 approaches. The first approach addresses water quality through voluntary watershed/water quality planning and management activities while the second approach is designed to address water quality through development of TMDLs. The strategy was designed to build upon existing water quality programs and to support watershed efforts of volunteer and non-profit organizations. Since 1995, the Committee has been conducting activities set forth in the strategy designed to implement programs aimed at protecting and improving water quality. These activities include Geographic Information System (GIS) watershed inventory, water quality assessment, watershed pollutant potential and prioritization, stormwater monitoring, Best Management Practices (BMP) Implementation projects, and public education/outreach. A summary of these activities can be found in *Phase I and II Report, Christina River Basin Water Quality Management Strategy, May 1998* and *Phase III Report, Christina Basin Water Quality Management Strategy, August 5, 1999.* These reports also describe the ongoing efforts to provide pollution control and restore water quality within the basin.

Concurrent with the water quality improvement activities taking place within the basin, EPA was sued for alleged violations of the Clean Water Act (CWA), the Endangered Species Act (ESA), and the Administrative Procedures Act (APA). On January 24, 1996, the American Littoral Society and the Public Interest Research Group filed a complaint (C.A. No. 96-489) in the U.S. District Court of Pennsylvania, as amended on April 17, 1996, against EPA for failure to comply with Sections 303(d) and (e) of the CWA, Section 7 of the ESA, and for alleged acts and omissions in violation of the APA. Likewise, on August 23, 1996 the American Littoral Society and Sierra Club filed a complaint in the U.S. District Court of Delaware against EPA (C. A. No. 96-5920) for failure to comply with Sections 303(d) and (e) of the CWA and alleged acts and omissions in violation of the APA. An additional complaint was filed on April 18, 1997 alleging further violations of the CWA and Section 7 of the ESA. These actions in Pennsylvania and Delaware were settled through Consent Decree (CD) entered on April 9, 1997 and August 9, 1997, respectively. Only the CD in Delaware set forth specific actions and expectations relating to TMDLs in the Christina River Basin. According to the settlement, Delaware was required to establish Step I TMDLs for all water quality limited segments, except for those impaired by bacteria, for Brandywine Creek, Christina River, Red Clay Creek and White Clay Creek by December 31, 1999. The basis of the multi-step approach stems from acknowledging existing water quality improvement activities occurring in the basin as well as the technical difficulties in developing complex TMDLs on a watershed scale. The Step I TMDLs are designed to address low-flow conditions while Step II will address will address high-flow conditions.

The CD also requires Delaware to establish the Step II TMDL by December 31, 2004. Pursuant to the CD, EPA is required to establish TMDLs within 1 year should Delaware fail to do so.

In response to the requirement to establish TMDLs, Delaware, in cooperation with the CBWQMC, identified the need for a scientific modeling tool to investigate water quality impairments related to the development of TMDLs in the basin. Tetra Tech, already under contract to EPA (Contract No. 68-C7-0018), was asked to provide regional TMDL watershed analysis and support within the Christina Basin. The original work plan (work assignment 0-03) was approved August 28, 1997 with the purpose of providing a calibrated water quality model for nutrients and dissolved oxygen for the Christina Basin to be used by DNREC and PADEP in establishing TMDLs. The model would be calibrated for critical, low-flow summer period, use all available information, and include both point and nonpoint sources. The WASP5[1] model was envisioned as the analytical tool, however, EFDC[2] was used after considering the complexity of the basin and the need to link this model with the HSPF[3] model being developed by USGS to characterize high-flow conditions. The work plan was further expanded on April 20, 1999 to include additional reaches in Delaware and allow for further validation of the model.

Following DNREC's request for scientific modeling support, a Model/Technical group was formed to develop the scientific modeling tool within the basin. Members who participated in this effort include representatives from DNREC, PA DEP, EPA, DRBC, USGS and Tetra Tech. After Tetra Tech began providing TMDL watershed analysis and support in 1998, the model/technical group met on a consistent basis in order to develop the modeling tool in support of the requirement to establish TMDLs for step 1 by December 31, 1999. In September 1998, when it became apparent that the model development was behind schedule, and at the request of Delaware and Pennsylvania, the DRBC agreed, by resolution, to hire Widener University to determine TMDLs once the model was completed. Unfortunately, due to the complexity of the modeling effort and various unforseeable difficulties, the model/technical group was unable to provide an adequate model for use in the development of TMDLs by December 31, 1999. Under the requirements of the CD, it then became EPA's responsibility to develop and establish the TMDL and provide the public participation activities by December 15, 2000.

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[1] Ambrose, R.B., T.A. Wool, and J.L. Martin. 1993. The water quality analysis and simulation program, WASP5 version 5.10. Part A: Model documentation. U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory, Athens, GA.

[2] Hamrick, J.M. 1992. A three-dimensional environmental fluid dynamics computer code: theoretical and computational aspects. SRAMSOE #317, The College of William and mary, Gloucester Point, VA.

[3] Bicknell, B.R., J.C. Imhoff, J.L. Kittle, A.S. Donigan, and R.C. Johanson. 1993. Hydrological Simulation Program-FORTRAN (HSPF): User's manual for release 10.0. EPA 600/3-84-066. Environmental Research Laboratory, U.S. Environmental Protection Agency, Athens, GA.

III. Christina Basin Water Quality

In addition to the legal, statutory, and regulatory requirements of identifying water quality limited segments and establishing TMDLs, there is a more fundamental and compelling philosophical basis for addressing water quality in the Christina Basin. The purpose of the Clean Water Act, and other similar legislation, is to guarantee that the chemical, physical, and biological integrity of the Nation's waters are restored and remain intact. These critical, but often delicate natural resources, can be easily degraded by anthropogenic and other sources of pollution which can affect the quality of life, health, and vitality of citizens in the basin. Even more fundamental to this action is the desire all citizens have to sustain the diverse human, ecological, aesthetic, and recreational resources of the watershed. While it is often times extremely difficult to attach a precise economic value to natural resources such as the Nation's waters, it is equally difficult to deny the benefits gained by restoring and maintaining the Nation's waters. Actions such as these become even more critical given that 75% of the public water supply for residents in New Castle County, Delaware and much of the water supply withdrawals in Chester County, Pennsylvania originate in waters from the Christina Basin. Furthermore, it is extremely likely that further development will take place in the basin which could potentially have negative impacts on water quality. Establishing water quality targets will allow progress while ensuring water quality integrity. That said, EPA feels it is necessary to characterize the past and current condition of water quality in the basin as well as assess available data in order to demonstrate the need to establish TMDLs. Apeendix A of this report describes in detail the existing water quality during low-flow. The data assessment discussion developed by John Davis of Widener University, in draft form for the DRBC TMDL determination, has been included verbatim from the "*Preliminary Draft TMDL Document*" provided to DRBC on June 7, 1999.

IV. Summary and Source Assessment

The Christina River Basin (Hydrologic Unit Code HUC 02040205) covers an area of 564.06 square miles and is located in Chester County, Pennsylvania, New Castle County, Delaware, and a small portion of Cecil County, Maryland (Figure 1). The major streams in the watershed include the upper Christina River (tidal and nontidal), Brandywine Creek (tidal and nontidal), Red Clay Creek, and White Clay Creek (tidal and nontidal). The basin drains to the tidal Delaware River at Wilmington, Delaware. The streams in the basin are used for municipal and industrial water supplies as well as for recreational purposes. The portions included in the model appear as the thick or outlined segments of the streams in figure 1.

The watershed is composed of diverse land uses including urban, rural, and agricultural areas. The overall land use distribution within the basin is summarized in table 1 below.

Table 1, Land Use Summary (acres)

Land Use	Delaware/ Maryland	Pennsylvania	Total	%
Urban/Suburban	87	108	195	34
Agricultural	18	160	178	31
Open Space/Protected Lands	21	5	26	5
Wooded	37	123	160	28
Water/other	3	3	6	2
Total	166	399	565	100

The major urban areas in the watershed include greater Wilmington and Newark, Delaware, and the Pennsylvania towns of West Chester, Downingtown, Kennett Square, Coatesville, Parkesburg, Honeybrook, Avondale, and West Grove.

There are 122 National Pollutant Discharge Elimination System (NPDES) discharges included in the Christina River Basin analysis (see Table 2 and Figure 2). The discharges range in type and size from small single resident discharges (about 500 gpd) to large industrial and municipal wastewater treatment plants (WWTPs) with effluent flow rates in the range of 1 to 7 mgd. The largest NPDES facilities discharging to the freshwater streams in the basin are Downingtown (permitted flow of 7.00 mgd), Sonoco (3.00 mgd), West Chester Borough (1.80 mgd), Lukens Steel (1.00 mgd), Coatesville (3.85 mgd), South Coatesville (0.39 mgd), Kennett Square (1.10 mgd), and Avondale (0.30 mgd). There are 7 NPDES facilities with permitted flow rates in the 10-90 mgd range that discharge to the tidal Delaware River portion of the model, with the largest being the City of Wilmington (90 mgd).

V. Problem Identification and Understanding

In response to the requirements of Section 303(d) of the CWA, the PA DEP and DE DNREC listed multiple Christina Basin waterbodies on their 1998 303(d) lists' of impaired waterbodies based on available information. Pennsylvania identified 24 stream segments on their 1998 303(d) lists (Table 3) while Delaware identified 15 stream segments on their 303(d) list (Table 4) as not meeting water quality standards for nutrients and low dissolved oxygen within the Christina River basin. Pursuant to the CD in Delaware, those 15 stream segments were given high priority. Likewise, Pennsylvania identified 23 of the 24 listed segments as high priority. A number of monitoring stations are located throughout the Christina River watershed within the listed waters (Figures 3 and 4). Data from these stations were used to determine the impairment and inclusion on the 303(d) lists based on the number of values exceeding water quality standards for dissolved oxygen. Excessive nutrients, organic enrichment, and low DO are specified as the causes of impairment in the various listed stream segments. The pollutant sources are varied and include industrial and municipal point sources, pasture lands, crop lands, and highway maintenance runoff. An extensive data assessment is provided in Appendix A.

It should be noted that this TMDL effort includes waterbodies or segments which have not been listed as impaired on the State's 303(d) lists. The logical reaction to this would be to ask the question, "Why develop and establish a TMDL for those waterbodies if they are not listed." The answer to this question stems from the underlying principles of the Watershed Protection Approach advocated by EPA. The Watershed Protection Approach is governed by the principle that many water quality and ecosystem problems are best solved at the watershed levels rather than on an individual waterbody or discharger level. This approach provides the ability to target priority problems, promote broader stakeholder involvement, integrate solutions which use all available expertise, and measure success through the use of data and monitoring. Managing water resources on a watershed basis makes sense environmentally, financially, and socially.

As indicated in the data assessment of Appendix A, the nutrient concentrations of the tidal Christina River are heavily influenced by tributary loads from the Brandywine Creek, Red and White Clay creeks, and nontidal Christina river. The data analysis also indicates that dissolved oxygen concentrations within the tidal Christina River violate both the minimum and daily average water quality standards during critical conditions. In addition to the influential nutrients loads from tributaries, spatial data analysis indicates that high levels of phytoplankton biomass are likely the result of transport from inland tributaries. In any case, the nutrient and biomass loadings from inland tributaries potentially contribute to the DO water quality standards violations within the tidal Christina River. This further justifies the need to consider sources of pollutants and tributaries on a watershed basis, regardless of whether that waterbody is explicitly listed on the State's 303(d) list.

Table 3, Christina River Basin stream reaches on the PA 1998 303(d) list

Watershed	Stream ID	Segment ID	Miles	Source of Impairment	Cause of Impairment
Brandywine Creek	00004	27	1.28	other	nutrients
Buck Run	00131	50	1.77	municipal point source	nutrients, low DO
Sucker Run	00202	970930-1437-GLW	6.78	agriculture	nutrients
W.Br. Brandywine Cr.	00085	970618-1118-GLW 970618-1340-GLW 970619-1222-GLW 970619-1345-GLW	2.98 3.57 5.51 3.99	agriculture	nutrients
Broad Run	00434	971209-1445-ACW	4.10	hydromodification, agriculture	organic enrichment, low DO, nutrients
E.Br. Red Clay Creek	00413	971023-1050-MRB 971204-1400-ACW	6.53 5.09	agriculture	organic enrichment, low DO
E.Br. White Clay Creek	00432	970409-1130-MRB 970506-1320-MRB 970508-1430-ACE 971113-1335-GLW 971119-1116-GLW 971120-1331-GLW	6.07 8.61 2.44 3.10 1.21 8.12	agriculture	nutrients nutrients organic enrichment, low DO organic enrichment, low DO nutrients nutrients
Egypt Run	00440	970508-1245-ACE	3.66	agriculture	organic enrichment, low DO
Indian Run	00475	115	1.09	agriculture, municipal point source	nutrients
Middle Br. White Clay	00462	115	17.33	agriculture, municipal point source	nutrients
Red Clay Creek	00374	971203-1400-ACW	0.76	agriculture	organic enrichment, low DO
Trout Run	00402	970506-1425-MRB	2.74	agriculture	nutrients
Walnut Run	00435	971209-1445-ACW	1.39	agriculture, hydromodification	organic enrichment, low DO, nutrients
W.Br. Red Clay Creek	00391	971023-1145-MRB	4.58	agriculture	organic enrichment, low DO
White Clay Creek	00373	971216-1230-GLW	1.13	agriculture	nutrients

Table 4, Christina River Basin stream reaches on the DE 1998 303(d) list

Waterbody ID	Watershed Name	Segment	Miles	Pollutants/Stressor	Probable Sources
DE040-001	Brandywine Creek	Lower Brandywine	3.8	nutrients	PS, NPS, SF
DE040-002	Brandywine Creek	Upper Brandywine	9.3	nutrients	PS, NPS, SF
DE260-001	Red Clay Creek	Mainstem	12.8	nutrients	PS, NPS, SF
DE260-002	Red Clay Creek	Burroughs Run	4.5	nutrients	NPS
DE320-001	White Clay Creek	Mainstem	18.2	nutrients	PS, NPS
DE320-002	White Clay Creek	Mill Creek	16.6	nutrients	NPS
DE320-003	White Clay Creek	Pike Creek	9.4	nutrients	NPS
DE320-004	White Clay Creek	Muddy Run	5.8	nutrients	NPS
DE120-001	Christina River	Lower Christina	1.5	nutrients, DO	NPS, SF
DE120-002	Christina River	Middle Christina River	7.5	nutrients	NPS, SF
DE120-003	Christina River	Upper Christina River	6.3	nutrients	NPS, SF
DE120-003-02	Christina River	Lower Christina Creek	8.4	nutrients	NPS
DE120-005-01	Christina River	West Branch	5.3	nutrients	NPS
DE120-006	Christina River	Upper Christina Creek	8.3	nutrients	NPS
DE120-007-01	Christina River	Little Mill Creek	12.8	nutrients, DO	NPS, SF

PS= point source; NPS = nonpoint source; SF=superfund site

Excess nutrients in a waterbody can have many detrimental effects on designated or existing uses, including drinking water supply, recreational use, aquatic life use, and fishery use[4]. Eutrophication, a term usually associated with the natural aging process experienced by lakes, describes the excessive nutrient enrichment of streams and rivers which can experience an undesirable abundance of plant growth, particularly phytoplankton (photosynthetic microscopic organisms (algae)), periphyton (attached benthic algae), and macrophytes (large vascular rooted plants). Photosynthesis and respiration of these plants as well as the microbial breakdown of dead plant matter contribute to wide fluctuations in the dissolved oxygen levels in streams. The impact of low DO concentrations or of anaerobic conditions is reflected in an unbalanced ecosystem, fish mortality, odors, and other aesthetic nuisances[5]. These types of impairments interfere with the designated uses of waterbodies by disrupting the aesthetics of the river, causing harm to inhabited aquatic communities, and causing violations of applicable water quality criteria. Figure 5 below shows the interrelationship of the major processes which affect DO.

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[4] U.S. Environmental Protection Agency. 1999. Protocol for Developing Nutrient TMDLs. Pg 2-1. EPA 841-B-99-007. Office of Water (4503F). U.S. EPA, Washington D.C. 135pp.

[5] Thomann, R.V., J.A. Mueller. 1987. Principles of Surface Water Quality Modeling. HarperCollins Publishers, Inc. Section 6.1.

The presence of aquatic plants in a waterbody can have a profound effect on the DO resources and the variability of the DO throughout a day or from day to day[6]. Growing plants provide a net addition of dissolved oxygen to the stream on an average daily basis through photosynthesis, yet respiration can cause low dissolved oxygen levels at night that can affect the survival of less tolerant fish species. This is due to the photosynthetic and respiration processes of aquatic plants which can cause large diurnal variations in DO that are harmful to fish. Photosynthesis is the process by which plants utilize solar energy to convert simple inorganic nutrients into more complex organic molecules[7]. Due to the need for solar energy, photosynthesis only occurs during daylight hours and is represented by the following simplified equation (proceeds from left to right):

$$\underset{\text{(Carbon Dioxide)}}{6CO_2} \quad + \quad \underset{\text{(Water)}}{6H_20} \quad \text{<----------->} \quad \underset{\text{(Sugar)}}{C_6H_{12}O_6} \quad + \quad \underset{\text{(Oxygen)}}{6O_2}$$

In this reaction, photosynthesis is the conversion of carbon dioxide and water into sugar and oxygen such that there is a net gain of DO in the waterbody. Conversely, respiration and decomposition operate the process in reverse and convert sugar and oxygen into carbon dioxide and water resulting in a net loss of DO in the waterbody. Respiration and decomposition occur at all times and are not dependent on solar energy. Also, if environmental conditions cause a die-off of either microscopic or macroscopic plants, the decay of biomass can cause severe oxygen depressions. Waterbodies exhibiting typical diurnal variations of DO experience the daily maximum in mid-afternoon during which photosynthesis is the dominant mechanism and the daily minimum in the predawn hours during which respiration and decomposition have the greatest effect on DO and photosynthesis is not occurring. Therefore, excessive plant growth, as a result of excessive nutrients, can affect a streams ability to meet both average daily and instantaneous dissolved oxygen standards[8].

Sediment oxygen demand (SOD) is due to the oxidation of organic matter in bottom sediments[9]. The organic matter originates from various sources including wastewater treatment facilities, leaf litter, organic-rich soil, or photosynthetically produced plant matter which settles and accumulates. In some instances, SOD can be significant portion of total oxygen demand, particularly in small streams where the effects may be more pronounced during low-flow or high temperature conditions[10].

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[6] Supra, footnote 5. Section 6.3.3.

[7] Chapra, S.C. 1997. Surface Water-Quality Modeling. WCB/McGraw-Hill. Section 19.1.

[8] U.S. Environmental Protection Agency. 1997. Technical guidance Manual for Developing Total Maximum Daily Loads, Book 2: Streams and Rivers, Part 1: Biochemical Oxygen Demand/Dissolved Oxygen and Nutrients/Eutrophication. Office of Water(4305). EPA 823-B-97-002. Section 4.2.1.2.

[9] Supra, footnote 7. Section 25

[10] Supra, footnote 8. Section 2.3.4.4.

BOD is a measure of the amount of oxygen required to stabilize organic matter in wastewater[11]. It is typically determined from a standardized test measuring the amount of oxygen available after incubation of the sample at 20°C for a specific length of time, usually 5 days. Conceptually, BOD requires a distinction between the oxygen demand of the carbonaceous material in waste effluents and the nitrogenous oxygen demanding component of an effluent[12]. Carbonaceous biochemical oxygen demand (CBOD) involves the breakdown of organic carbon compounds while nitrogenous biochemical oxygen demand (NBOD) involves the oxidation of ammonia to nitrate, commonly referred to as the nitrification process[13].

VI. Linkage Analysis

Thomann and Mueller[14] define a model as "a theoretical construct, together with assignment of numerical values to model parameters, incorporating some prior observations drawn from field and laboratory data, and relating external inputs or forcing functions to system variable responses." In order to evaluate the linkage between the applicable water quality criteria(endpoints) and the identified sources and establish the cause-and-effect relationship, EPA is utilizing the EFDC water quality model, which is a public domain surface water modeling system incorporating fully integrated hydrodynamic, water quality and sediment-contaminant simulation capabilities. EFDC is extremely versatile and can be applied in 1,2, or 3 dimensional simulation of rivers, lakes, and estuaries with coupled salinity and temperature transport. Further capabilities of the model include a directly coupled water quality-eutrophication and toxic contaminated sediment transport and fate models, integrated near-field mixing zone model, as well as pre and post-processing for input file creation, analysis, and visualization. The eutrophication component of EFDC can simulate the transport and transformation of 22 state variables including cyanobacteria, diatom algae, green algae, refractory particulate organic carbon, labile particulate organic carbon, dissolved carbon, refractory particulate organic phosphorus, labile particulate organic phosphorus, dissolved organic phosphorus, total phosphate, refractory particulate organic nitrogen, labile particulate organic nitrogen, dissolved organic nitrogen, ammonia nitrogen, nitrate nitrogen, particulate biogenic silica, dissolved available silica, chemical oxygen demand, dissolved oxygen, total active metal, fecal coliform bacteria, and macroalgae. The EFDC model has been applied in similar studies including the Peconic Estuary, the Indian River Lagoon/Turkey Creek, and the Chesapeake Bay system.

In order to ensure that the EFDC model is adequately representing the hydrodynamic and water quality processes of the Christina River Basin, separate calibration and validation of the model

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[11] Supra, footnote 8. Section 2.3.4.

[12] Supra, footnote 5. Section 6.3.1.

[13] Supra, footnote 7. Section 19.4.

[14] Supra, footnote 5. Section 1.2.1.

was performed to establish model robustness[15]. Calibration involves adjusting kinetic parameters within the model to achieve a specified level of performance in comparison to actual observed hydrodynamic and water quality data from the basin. The model calibration was executed over a period of 143 days from May 1 to September 21, 1997. EPA also validated the Christina River basin model to confirm and provide additional confidence that the model can be used as an effective prediction tool for a range of conditions other than those in the original calibration. During validation, the kinetic parameters which were adjusted during calibration remain fixed to evaluate the model accuracy in representing the basin. The model validation was executed over a period of 143 days from May1 to September 21, 1995. Point source loads during calibration and validation are representative of actual discharged loads as indicated on Discharge Monitoring Reports during the calibration or validation periods. Nonpoint source loads are based on STORET data, USGS water quality data, baseflow sampling, and data from interstate monitoring efforts during the calibration or validation periods. These loads represent contributions from nonpoint sources and form the basis of the load allocations.

EPA also provides an assessment of the calibration and validation quality. There are two general approaches for assessing the quality of a calibration: subjective and objective[16]. The subjective assessment typically involves visual comparison of the simulation with the data, as in time series plots for state variables, while the objective assessment utilizes quantitative measures of quality such as statistical measures of error. EPA includes both types of assessment and compares the Christina River basin model error statistics with those from other similar studies. A complete and more-detailed technical discussion regarding the EFDC model is available in the *Hydrodynamic and Water Quality Model of Christina River Basin Final Report, April 14, 2000.*

The calibrated and validated water quality model was used to confirm that the model was able to simulate the locations of the impaired stream segments on the 303(d) list. The model results from the 1997 calibration run were plotted on a map view of the Christina River basin and those model grid cells not meeting the daily average and minimum dissolved oxygen water quality criteria were highlighted (see Figures 6 and 7). The 1997 calibration results indicate that the daily average DO criteria were not met in portions of the tidal Christina River, tidal Brandywine Creek, tidal White Clay Creek, West Branch Christina River, West Branch Red Clay Creek, and Little Mill Creek (Figure 6). The 1997 calibration results also indicate that the minimum DO criteria were not protected in portions of the West Branch Red Clay Creek, Little Mill Creek, and tidal Brandywine Creek (Figure 7).

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[15] Supra, footnote 7. Section 18.1.5.

[16] Supra, footnote 7. Section 18.3.

A separate analysis was performed to investigate potential WQS violations during critical conditions. During this scenario, the NPDES point source discharges were set to their maximum permitted flows and concentrations and the model was run under 7Q10 stream flow conditions. Nonpoint source pollutant loads, as computed by multiple data sets, were developed to represent expected conditions and pollutant contributions during critical periods. The use of actual site-specific data to characterize nonpoint sources is appropriate and would essentially act to integrate past pollutant loading events. While the process of calibrating and validating the water quality model was dynamic, the critical condition analysis is representative of steady-state conditions. Tidal elevations at the north and south boundaries on the Delaware River were set using tidal harmonic constants derived from NOAA subordinate tide stations at Chester, Pennsylvania, and Reedy Point, Delaware. Map-view graphics were created to highlight problem areas (see Figures 8 and 9). The model results from the period of August 1 through August 31, when critical stream flows are most likely to occur, indicate that the daily average DO criteria will not be satisfied in portions of the West Branch Brandywine Creek, East Branch Brandywine Creek below Downingtown, Brandywine Creek main stem, West Branch Red Clay Creek, West Branch Christina River, and tidal Christina River. The model results also indicate that the minimum DO criteria will not be achieved in portions of the West Branch Brandywine Creek, East Branch Brandywine Creek below Downingtown, Brandywine Creek main stem, West Branch Red Clay Creek, tidal White Clay Creek, and West Branch Christina River.

While this TMDL analysis and subsequent allocation scenarios are designed to address low-flow, point source conditions, the analysis does not exclude land-based nonpoint sources from consideration. Addressing this critical condition establishes the baseline condition which point sources within the basin must comply with in order to achieve water quality standards. Contributions from nonpoint sources are assumed to be very small due to lack of precipitation-related events.

The stream reaches identified by the model as not meeting DO criteria are in general agreement with those on the 303(d) lists. EPA believes that the Christina River Basin model is an appropriate tool for understanding the current water quality problems in the basin, evaluating the linkage between cause-and-effect, and allocating pollutant to identified sources.

VII. Discussion of Regulatory Conditions

Federal regulations at 40 CFR Section 130 require that TMDLs must meet the following 8 regulatory conditions:

1) The TMDLs are designed to implement applicable water quality standards.
2) The TMDLs include a total allowable load as well as individual waste load allocations and load allocations.
3) The TMDLs consider the impacts of background pollutant contributions.
4) The TMDLs consider critical environmental conditions.
5) The TMDLs consider seasonal environmental variations.
6) The TMDLs include a margin of safety.
7) The TMDLs have been subject to public participation.
8) There is reasonable assurance that the TMDLs can be met.

EPA provides the following discussion to demonstrate how the Christina River Basin TMDL meets those 8 regulatory requirements.

1) The TMDLs are designed to implement applicable water quality standards.

Target Analysis

The purpose of the target analysis is to define the relationship between the designated uses, numeric measures of success, and pollutant loading. Water Quality Standards define the water goals for a waterbody, or portion thereof, by designating the use or uses to be made of the water, by setting criteria necessary to protect the uses, and by protecting water quality through antidegradation provisions. These standards serve dual purposes: they establish water quality goals for specific a waterbody, and they serve as the regulatory basis for establishing water quality-based treatment controls and strategies beyond the technology-based levels of treatment required by sections 301(b) and 306 of the CWA[17].

Within the Christina River Basin, there are 4 regulatory agencies which have applicable water quality standards. The PA DEP, DE DNREC, and MDE have water quality standards which apply to

[17] U.S. Environmental Protection Agency. 1994. Water Quality Standards Handbook: Second Edition. Office of Water(4305). EPA 823-B-94-005a. Section 2.1.

those stream segments of the Christina River Basin located in Pennsylvania, Delaware, and Maryland, respectively. The DRBC[18] is an interstate agency which has the authority to establish water quality standards and regulate pollution activities within the Delaware River basin and therefore the Christina River basin. Tables 5 and 6 below summarizes the applicable water quality standards relating to dissolved oxygen and nutrients.

Table 5, Summary of Applicable Use Designations and DO Criteria

Agency	Designated Use	D.O. Criteria (mg/L)		Comments
		Daily avg.	Minimum	
PADEP	Warm water fish (WWF)	5.0	4.0	
	Cold water fish (CWF)	6.0	5.0	
	Trout stocking fishery (TSF)	6.0 5.0	5.0 4.0	Feb 15 - Jul 31 Aug 01 - Feb 14
	High Quality CWF		7.0	Special Protection Waters
	High Quality TSF	6.0	5.0	Special Protection Waters
	Exceptional value			Special Protection Waters
DNREC	Fresh waters	5.5*	4.0	*Average for June-September period shall not be less than 5.5 mg/L
	Cold water fish	6.5	5.0	Seasonal
	Marine waters	5.0	4.0	Salinity greater than 5.0 ppt
	Exceptional recreation or ecological significance			Existing or natural water quality
MDE	Fresh waters	5.0	5.0	Use I waters, DO must not be less than 5.0 mg/L at any time
DRBC	Resident game fish	5.0	4.0	
	Trout	6.0	5.0 7.0	 During spawning season
	Tidal: resident or anadromous fish	4.5		6.5 mg/L seasonal average during Apr 01 - Jun 15 and Sep 16 - Dec 31

[18] The DRBC was created by compact among Pennsylvania, New Jersey, New York, Delaware and the federal government in 1961.

Table 6, Summary of Nutrient Criteria

Parameter / Agency	Comments
Ammonia-Nitrogen	
PADEP	1-day and 30-day average ambient criteria are a function of pH and temperature for toxicity; Implementation Guidance document for Ammonia allocations for NBOD and Toxicity.
DNREC	No specific numeric criteria; Narrative statement for prevention of toxicity.
DRBC	NPDES effluents limited to a 30-day average of 20 mg/L as N.
Nitrate-Nitrogen	
PA DEP	Ambient criteria is maximum of 10 mg/L as N applied at the point of water supply intake, not at the point of an effluent discharge. For the case of an interstate stream, the state line shall be considered a point of water supply intake.
DNREC	Ambient nitrate criteria is maximum of 10 mg/L as N; provision for site-specific nutrient controls. The 303(d) rationale document cites 3.0 mg/L total nitrogen as guidance for impairment.
DRBC	No specific numeric criteria.
Phosphorus	
PA DEP	No specific numeric criteria are specified in the Pennsylvania Code, Title 25, Chapter 93 (Water Quality Standards). According to Chapter 95 (Wastewater Treatment Requirements), phosphorus effluent limits are set to a maximum of 2 mg/L whenever the Department determines that instream phosphorus alone or in combination with other pollutants contributes to impairment of designated stream uses.
DNREC	No specific numeric criteria; provision for site specific controls. The 303(d) rationale document cites 0.1 mg/L total phosphorus as guidance for use impairment.
DRBC	No specific numerical criteria.

Once the applicable use designation and water quality criteria are identified, the numeric water quality target or goal for the TMDL can be specified. Figure 10 below shows the applicable use designations for stream segments included in the Christina River TMDL. Using tables 5 and 6 and figure 10, the numeric water quality targets for dissolved oxygen can be discerned for each segment. While PA DEP, DE DNREC, MDE, and DRBC lack numeric water quality criteria for total nitrogen and total phosphorus, each Agency has narrative water quality criteria which can be interpreted to set surrogate criteria. Narrative water quality criteria are statements that qualitatively describe the desired water quality goal, otherwise known as the "free-from" statements. An example of an narrative criterion is "Waters of the state shall be free from toxics in toxic amounts". Given our scientific knowledge regarding the interrelationship of nutrients, BOD, SOD, and it's impact on dissolved oxygen, establishing numeric targets for total nitrogen and total phosphorus based on narrative criteria to support the attainment of the numeric dissolved oxygen criterion is appropriate. Likewise, developing waste load allocations for total phosphorus, total nitrogen, ammonia-nitrogen, CBOD, and DO for point sources to maintain adequate instream levels of dissolved oxygen is appropriate. Establishing numeric water quality endpoints or goals also provides the ability to measure the progress toward attainment of the water quality standards and to identify the amount or degree of deviation from the allowable pollutant load. The table below identifies the numeric water quality targets or endpoints for the Christina River Basin TMDL.

Table 7, Summary of TMDL endpoints

Parameter	**Target Limit**	**Reference**
Daily Average DO, freshwater, Pennsylvania	5.0 mg/L	Pennsylvania Water Quality Standards
Daily Average DO, freshwater, Delaware	5.5 mg/L	Delaware Water Quality Standards
Daily Average DO, tidal waters, Delaware	5.5 mg/L	Delaware Water Quality Standards
DO at any time, freshwater, Maryland	5.0 mg/L	Maryland Water Quality Standards
Minimum DO	4.0 mg/L	Pennsylvania and Delaware Water Quality Standards

While the ultimate endpoint for this TMDL analysis is to ensure that the water quality standards for dissolved oxygen are maintained throughout the Christina River Basin, it is necessary to determine if other applicable water quality criteria are met and maintained. Specifically, this applies to the Pennsylvania water quality standards for nitrate-nitrogen of 10 mg/l and ammonia-nitrogen which is based on temperature and pH. As a result of the pollutant load reductions necessary to maintain the water quality criteria for dissolved oxygen, the water quality standards for nitrate-nitrogen and ammonia-nitrogen of Pennsylvania are met throughout the Pennsylvania portion of the Christina Basin. Delaware water quality standards also set a numeric water quality criteria of 10 mg/l for nitrate-nitrogen. Similarly, the water quality standards for nitrate-nitrogen of Delaware are met throughout the Delaware portion of the Christina Basin. Delaware does not have numeric water quality criteria for ammonia-nitrogen, however, the analysis indicates that ammonia-nitrogen levels throughout the Delaware portion of the Christina Basin are consistent with the recommended EPA water quality criterion from Section 304(a) of the CWA. Maryland does not have numeric water quality standards for ammonia-nitrogen and nitrate-nitrogen.

Achieving these in-stream numeric water quality targets will ensure that the designated uses (aquatic life and human health uses (nitrate-nitrogen)) of waters in Pennsylvania, Delaware, and Maryland are supported during critical conditions.

2) The TMDLs include a total allowable load as well as individual waste load allocations and load allocations (Source Assessment).

Total Allowable Load

The total allowable load for each basin, as determined by the EFDC model, was calculated based on the segmentation of the model in order to better correspond with the 303(d) listing, ensure the integrity of each stream segment, and to allow pollution trading alternatives. Table 8 below identifies the total allowable load as well as the waste load allocations, load allocations, and margin of safety for each of the 16 stream segments of the model.

Deposition from atmospheric sources is also considered in the Christina River water-quality model. While atmospheric deposition may not be as important in the narrow stream channels, it could become more important in the open estuary waterbodies in the lower Christina and Delaware rivers. Atmospheric loads are typically divided into wet and dry deposition. Wet deposition is associated with dissolved substances in rainfall. The settling of particulates during non-rainfall events contributes to dry deposition. Observations of concentrations in rainwater are frequently available and dry deposition is usually estimated as a fraction of the wet deposition. The atmospheric deposition rates reported in the Long Island Sound Study (HydroQual 1991) and the Chesapeake Bay Model Study (Cerco and Cole 1994) as well as information provided by DNREC for Lewes, Delaware, were used to develop both dry and wet deposition loads for the EFDC model of the Christina River Basin. The dry atmospheric deposition rates are presented in Tables 7-8 and 7-9 of the model report. The loading rate for wet deposition of nutrients was computed internally by the model by multiplying the rainfall rate times the nutrient concentration during each model time step.

<u>Size-Based Equal Marginal Percent Removal Allocation Strategy</u>

The general theory of waste load allocations and more specifically, the size-based equal marginal percent removal (EMPR) allocation strategy that is used in this TMDL, is discussed in this section. While a complete and detailed understanding of the concepts discussed below is not essential to using the Christina Basin water quality model, a general appreciation of underlying principles will aid the user in applying the model and interpreting the results. The strategy presented in this section is based largely upon the document *Implementation Guidance for the Water Quality Analysis Model 6.3* (PDEP 1986).

The term "waste load allocation" refers to a specific set of circumstances in which two or more point source discharges are in sufficiently close proximity to one another to influence the level of treatment each must provide to comply with water quality standards. This definition is technically correct since without discharge interaction there is no need to share (i.e., to allocate) the assimilation capacity of the receiving water body. In a single discharge situation, all that needs to be done is to determine the level of treatment that must be provided to comply with water quality standards. The size-based EMPR analysis does this as a first step: (1) to determine if a waste load allocation situation exists; and if it does, (2) to assign waste load allocations to each of the discharges that is contributing to the water quality violation. A waste load allocation process should have three major objectives:

1) To assure compliance with the applicable water quality standards;
2) To minimize, within institutional and legal constraints, the overall cost of compliance;
3) To provide maximum equity (or fairness) among competing discharges.

The first objective, is fundamental to water quality and public health protection. It is an ethical statement that assumes the social, economic, and environmental benefits of water pollution control outweigh the associated costs. The overall wisdom of this approach, which legislatively mandated in the Federal Clean Water Act, is debatable, but beyond the scope and purpose of this discussion. In any case, by making this statement the implementation phase of water quality management is spared the task of demonstrating that benefits outweigh costs.

The second objective is a statement of the desirability of economic efficiency. Resources devoted to one purpose are not available for another use. This holds true whether the resources are of a public or a private nature. It therefore behooves a water quality management program to achieve water quality management goals with maximum economic efficiency (i.e., at least cost). It can be shown that maximum efficiency is achieved when the marginal cost of pollution abatement is the same for all participants. The marginal cost of wastewater treatment is related to the marginal rate of removal. If it is assumed that the marginal cost per unit of removal is the same for all discharges, then maximum economic efficiency is achieved when the marginal rate of removal for all discharges is the same. Institutional and legal constraints may prevent water quality programs from achieving optimal economic efficiency. Nevertheless, maximum efficiency within existing institutional and legal constraints should be pursued.

The third objective is a social statement that goes hand in hand with the second objective. Maximizing economic efficiency would by definition, provide for maximum equity. The desirability of equity, especially in a regulatory program, among individual (and potentially competing) members of society is a reasonably well accepted concept. The specific definition of when (or how) equity is to be achieved is, however, open to debate and interpretation. The wasteload allocation strategy employed in this TMDL is that of equal marginal percent removal. It is based on the premise that all discharges, whether or not they are part of a waste load allocation scenario, should provide sufficient treatment to comply with water quality standards, and that some discharges, because they are part of an allocation scenario, must provide additional treatment, due to the cumulative impact that they and nearby discharges have on the receiving stream. The strategy is similar in most respects to more traditional uniform treatment approaches, where all discharges provide the same degree of treatment. The major difference is in the selection of the baseline condition for the waste load allocation process. In most traditional uniform treatment approaches all discharges that are believed to be part of the waste load allocation scenario start at the same treatment level. The traditional approach introduces economic inefficiencies and inequities into the waste load allocation process because it fails to consider the individual impact that each discharge has on the receiving stream. This individual impact is a function of the discharge size and location. The practical result of failing to take these factors into consideration is to impose unnecessarily stringent treatment requirements on smaller dischargers, solely because they happen to be in the vicinity of a larger discharge. This imposes higher than necessary costs on these smaller discharges, and in effect, causes them to subsidize discharges that have a greater impact on water quality. At the same time, uniform treatment does not significantly improve overall water quality.

In the size-based EMPR strategy, the baseline condition for each discharge is the level of treatment the discharge must provide if it is the only discharge to the receiving stream. This level of treatment is water quality based for this TMDL. It is a function of the discharge size and location. In selecting this baseline condition, there are no assumptions made as to whether a discharge is or is not part of an allocation scenario.

Once the baseline condition for each discharge is established, a determination is made of whether additional treatment is needed because of the cumulative impact of multiple discharges. The discharges are added back into the model one at a time, based on the size of their load (i.e., kg/day of CBOD). The model is then run again. If additional treatment is necessary, then all discharges contributing to the water quality standard violations are reduced by equal percentages, starting from their individual levels of treatment at the end of the previous model run. Thus, the marginal rate of removal for all affected discharges is the same in any given model run, while the overall rate of removal for each may be different.

Another difference between the traditional uniform treatment approach and the size-based EMPR strategy is in the determination of which discharges are part of the wasteload allocation scenario. In the uniform treatment approach, it is commonly assumed that the wasteload allocation segment starts at the first discharge that adversely affects in-stream conditions, and extends downstream to the point where the stream returns to background conditions. It is not entirely clear whether this assumption is absolutely required, or is merely a matter of convenience. In either case, the specification of a return to background stream quality tends to extend the allocation segment to include discharges that may not be part of the allocation at all. This further increases the economic inefficiency and inequity of uniform treatment solutions.

The size-based EMPR waste load allocation strategy does not require any assumptions with regard to a return to background stream conditions. The strategy determines the downstream limit of the allocation problem based on compliance with water quality standards. These features, combined with the different baseline condition makes size-based equal marginal percent reduction a more cost-efficient and equitable waste load allocation strategy than the traditional methods.

Christina River Basin Allocation Process

The first consideration is to determine what time period to use for the allocation scenarios. Only the results from the model period August 1-31 were analyzed to determine the daily average DO and minimum DO for comparison to water quality standards and to direct the allocation scenarios. This time period was selected as most representative of when critical conditions are expected to occur within the system. The model was run for a sufficient period to allow for: (1) the nutrient loads to transport their way through system; (2) the predictive sediment diagenesis model to attain dynamic equilibrium; and (3) the algae to react to the availability of nutrients.

The size-based EMPR allocation process relies on 3 levels of analysis for the Christina River basin. Level 1 involves analyzing each NPDES point source individually to determine the baseline levels of treatment necessary to achieve water quality standards for daily average and minimum DO.

The point sources not being considered individually and the tributaries are set to the baseline conditions listed in Table 9 below. This allows the in-stream flow to remain at 7Q10 levels and provides no net impact on water quality from the point sources not being considered individually. Level 2 involves multiple model runs in which the NPDES discharges are added to the model one at a time based on the size of their CBOD load to determine the waste load allocations necessary to achieve water quality standards. If necessary, Level 3 involves analyzing the NPDES discharges outside the Christina River basin (i.e., those discharging to the tidal Delaware River) in order to meet water quality standards in the tidal Christina River.

The ultimate endpoints of this low-flow TMDL are the daily average and the minimum dissolved oxygen criteria for the various stream segments in the study area. Dissolved oxygen concentrations vary throughout the course of a 24-hour day and tend to follow a general sinusoidal pattern with the lowest point occurring just before sunrise and the highest value occurring in the afternoon. In general, controlling CBOD has a greater impact on the daily average DO than on the diel DO range. Depending on whether a system is nitrogen or phosphorus limited, the available nitrogen or phosphorus influences the diel DO range due to the impact on algae and periphyton growth kinetics. The model calibration and validation indicated that phosphorus is the limiting nutrient in the freshwater streams in the Christina River basin (USEPA 2000). The allocation process will proceed by reducing the CBOD, nitrogen, and phosphorus loads from the NPDES point sources in equal percentages until the daily average DO criteria are satisfied. After this is accomplished, if the minimum DO criteria have not been met, then the phosphorus loads will be further controlled until the diel DO range is reduced sufficiently to satisfy the minimum DO criteria.

Since this first phase of the TMDL deals with low-flow conditions only, by definition very little nonpoint source load from land-based sources will be entering the system during drought conditions. The nonpoint source flows from peripheral tributaries and groundwater sources are considered to be at baseline (i.e., background) conditions. The baseline concentrations for the various water quality parameters were determined from all data in the STORET database for the period 1988 to 1998. The 10 percentile concentration values were assumed to be indicative of the nonpoint source contributions during the 7Q10 low-flow period. The concentrations were within the range of expected values for watersheds in the eastern United States according to Omernik (1977). The baseline concentrations for total nitrogen and total phosphorus are presented in Table 9.

Table 9. Baseline Concentrations of Nitrogen and Phosphorus for Christina River TMDL

Subwatershed	Total Nitrogen (mg/L)		Total Phosphorus (mg/L)	
	Baseline	Omernik (1977) (67% range)	Baseline	Omernik (1977) (67% range)
Main stem and East Branch Brandywine Creek	1.56	0.33 - 6.64	0.01	0.008 - 0.251
West Branch Brandywine Creek	2.44	0.33 - 6.64	0.03	0.008 - 0.251
Red Clay Creek	2.65	0.33 - 6.64	0.05	0.008 - 0.251
White Clay Creek	2.31	0.33 - 6.64	0.02	0.008 - 0.251
Christina River	1.08	0.33 - 6.64	0.02	0.008 - 0.251

Level 1 Allocation Results - Baseline Allocations

The first level of the size-based EMPR allocation involved considering each NPDES discharge individually to determine if water quality standards for DO were met. Those discharges not considered individually were set to the baseline conditions in Table 9. This allowed the in-stream flow to remain at 7Q10 levels and created no net impact on water quality from the point sources not being considered individually. If water quality standards were not met, then CBOD, nitrogen, and phosphorus for the individual point source were reduced in 5% increments until standards were achieved. Of the 99 NPDES point sources in the Christina River watershed, 87 of them are small having flow rates of 0.25 mgd or less. In order to avoid making 87 individual model runs to determine whether a Level 1 allocation was needed, all the small NPDES discharges were grouped into a single model run. The model results for this run indicated that the water quality standard for daily average DO and minimum DO were protected at all locations in the basin. Thus, if as a group there were no violations of the DO standard for the small discharges, then individually there would be no violations.

Next, the remaining 12 large NPDES discharges were analyzed individually. Of these 12, only four indicated violations of the DO standards: (1) PA0026531 (Downingtown) on the East Branch Brandywine Creek, (2) PA0026859 (Coatesville City) on the West Branch Brandywine Creek, (3) PA0024058 (Kennett Square) on West Branch Red Clay Creek, and (4) MD0022641 (Meadowview Utilities) on West Branch Christina River. The Downingtown facility caused violations of the minimum DO standard but not the daily average DO standard. The other three facilities caused violations of both the daily average and minimum DO standards (see Figures 11 and 12). The Level 1 load reductions necessary to achieve compliance with the water quality standards for DO are shown in Table 10.

Table 10. Level 1 Baseline Allocations

NPDES Facility	Flow (mgd)	Existing Permit Limits			Level 1 Allocation Limits			Level 1 Percent Reduction		
		CBOD5 (mg/L)	NH3-N (mg/L)	TP (mg/L)	CBOD5 (mg/L)	NH3-N (mg/L)	TP (mg/L)	CBOD5	NH3-N	TP
PA0026531	7.0	10	2.0	2.0	10	2.0	1.6	0%	0%	20%
PA0026859	3.85	15	2.0	2.0	10.5	2.0	1.0	30%	0%	50%
PA0024058	1.1	25	3.0	7.5*	17.5	2.1	1.35	30%	30%	82%
MD0022641	0.7	22	6.45*	1.0	14.08	2.0	1.0	36%	69%	0%

* no permit limits, values shown are based on monitoring data

Level 2 Allocation Results

The second level of the size-based EMPR allocation strategy involved adding the discharges one at a time based on the size of Level 1 baseline CBOD allocations (kg/day) and performing waste load allocations to those stream segments indicating violations of the DO water quality standards. The daily average and minimum DO results of the initial Level 2 run are shown in Figures 13 and 14. It is apparent that the DO water quality standards are not being met in the East Branch Brandywine Creek, West Branch Brandywine Creek, West Branch Red Clay Creek, and West Branch Christina River with the two largest dischargers added to each of these stream reaches. The allocation proceeded by running the water quality model in an iterative fashion by reducing CBOD, NH3-N, and TP in 5% intervals for all NPDES discharges upstream of the farthest downstream model grid cell indicating a DO violation. Once water quality standards were achieved at the 5% increment level, the allocations were fine tuned in 1% increments. After the allocations were fine tuned, the next largest discharger was added to the stream reach and the process was repeated until all dischargers were included in the analysis.

No allocations were made to point sources on the main stem Brandywine Creek until the stream segments on the East and West Branches were first in compliance with water quality standards. The small residence discharges (0.0005 mgd), groundwater cleanup discharges, and water filtration plant backwash facilities were not included in the allocation analysis since (1) the small facilities will have negligible impact on the overall water quality and (2) it is not economically feasible to implement controls on these small facilities. Furthermore, filtration backwash facilities only discharge as needed and not on a continual basis. The Level 2 allocation results are presented in Table 11 and are shown in Figures 15 and 16. It can be seen that there are no violations of the daily average DO or minimum DO criteria at any point inside the Christina River Basin. Thus, a Level 3 allocation will not be necessary for the tidal Christina River.

Table 11. Level 2 Allocations

NPDES Facility	Flow (mgd)	Level 1 Allocation Limits			Level 2 Allocation Limits			Level 2 Percent Reduction		
		CBOD5 (mg/L)	NH3-N (mg/L)	TP (mg/L)	CBOD5 (mg/L)	NH3-N (mg/L)	TP (mg/L)	CBOD5	NH3-N	TP
East Branch Brandywine Creek										
PA0026018	1.8	25	2.5	2.0	23.48	2.35	1.88	6%	6%	6%
PA0043982	0.4	25	0.10*	2.0	22.27	0.10**	1.78	11%	0%	11%
PA0012815	3.0	34	6.0	1.0	20.06	3.54	0.45	41%	41%	55%
PA0026531	7.0	10	2.0	1.6	5.90	1.18	0.73	41%	41%	64%
PA0030228	0.0225	7.0	1.0	3.0	6.86	0.98	2.94	2%	2%	2%
PA0054917	0.003	7.0	1.0	1.0	6.86	0.98	0.98	2%	2%	2%
PA0050458	0.0351	10	3.0	1.0	9.80	2.94	0.98	2%	2%	2%
PA0050547	0.0375	10.0	3.0	1.0	9.80	2.94	0.98	2%	2%	2%
West Branch Brandywine Creek										
PA0029912	0.1	25	20.0	2.0	24.72	19.78	1.98	1%	1%	1%
PA0036987	0.39	25	7.0	2.0	24.72	6.92	1.98	1%	1%	1%
PA0026859	3.85	10.5	2.0	1.0	8.08	1.54	0.77	23%	23%	23%
PA0011568-001	0.5	30*	0.50*	0.30*	23.10	0.50**	0.30**	23%	0%	0%
PA0011568-016	0.5	30*	0.50*	0.30*	23.10	0.50**	0.30**	23%	0%	0%
PA0055697	0.049	25	1.50*	2.0	24.25	1.46	1.94	3%	3%	3%
PA0044776	0.6	15	3.0	2.0	13.83	2.77	1.84	8%	8%	8%
West Branch Red Clay Creek										
PA0024058	1.1	17.5	2.1	1.35	16.62	1.99	1.28	5%	5%	5%
PA0057720-001	0.05	10	2.0	2.0*	9.50	1.90	1.90	5%	5%	5%
Christina River West Branch										
MD0022641	0.7	14.08	2.0	1.0	12.8	1.82	1.0	9%	9%	0%
MD0065145	0.05	15	4.52*	1.0	13.65	4.11	1.0	9%	9%	0%

* no permit limits, values shown are based on typical characteristics or monitoring data
** no allocation, concentrations are at practical limits of control

Waste load Allocations

Federal regulations at 40 CFR 130.7 require TMDLs to include individual WLAs for each point source. Tables 12-27 outline the individual WLAs for those dischargers in the Christina River Basin. Of the 122 NPDES facilities considered, only those 19 dischargers considered during the Level 1 and Level 2 EMPR analysis require reductions to their NPDES permit limits for those pollutants listed above.

Load Allocations

According to federal regulation at 40 CFR 130.2(g), load allocations are best estimates of the loading, which may range from reasonably accurate estiamtes to gross allottments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible natural and nonpoint source loads should be distinguished.

Nonpoint source loads within the Christina River basin model are based on monitoring data from STORET, USGS water quality data, baseflow samples taken in 1997, and interstate monitoring data collection efforts. The loads represent expected low-flow contributions from subwatersheds according to the delineation of the 39 subwatersheds in the HSPF model currently being developed by USGS. This will allow the HSPF model to be directly linked to the EFDC model to investigate seasonality and address high-flow situations. Those data sets were used to develop characteristic loads of parameters of concern (carbon, nitrogen, phosphorus, DO, algae) for each of the 39 subwatershed as delineated by the HSPF model. Load allocations were based on actual site-specific data and are broken down by subwatershed in tables 12-27 below.

Allocations Scenarios

EPA realizes that the breakout of the total loads below for carbonaceous biochemical oxygen demand (5-day), ammonia nitrogen, total nitrogen, total phosphorus and dissolved oxygen to the point sources and nonpoint sources is one allocation scenario. As implementation of the established TMDLs proceed, the States and DRBC may find that other combinations of point and nonpoint source allocations are more feasible and/or cost effective. However, any subsequent changes in the TMDL must conform to gross waste load and load allocations for each segment and must ensure that the biological, chemical, and physical integrity of the waterbody is preserved.

Federal regulations at 40 CFR 122.44(d)(1)(vii)(B), require that, for an NPDES permit for an individual point source, the effluent limitations must be consistent with the assumptions and requirements of any available WLA for the discharge prepared by the State and approved by EPA. EPA has authority to object to the issuance of an NPDES permit that is inconsistent with WLAs established for that point source. To ensure consistency with these TMDLs, as NPDES permits are issued for the point sources that discharge the pollutants of concern to the Christina River Basin, any deviation from the WLAs described herein for the particular point source must be documented in the permit Fact Sheet and made available for public review along with the proposed draft permit and the Notice of Tentative Decision. The documentation should; 1) demonstrate that the loading change is consistent with the goals of the TMDL and will implement the applicable water quality standards, 2) demonstrate that the changes embrace the assumptions and methodology of these TMDLs, and 3) describe that portion of the total allowable loading determined in the TMDL report that remains for other point sources (and future growth where included in the original TMDL) not yet issued a permit under the TMDL. It is also expected that the States will provide this Fact Sheet, for review and comment, to each point source included in the TMDL analysis as well as any local and State agency with jurisdiction over land uses for which load allocation changes may be impacted. EPA believes that this gives flexibility to the State agencies to address point source trading within the NPDES permitting process. However, should these trading activities result in changes to the total loading by basin or subwatershed segment, then EPA would expect that revisions would be necessary and the States or DRBC would need to follow the formal TMDL review and approval process.

In addition, EPA regulations and program guidance provides for effluent trading. Federal regulations at 40 CFR 130.2 (I) state: "If Best Management Practices (BMPs) or other nonpoint source pollution controls make more stringent load allocations practicable, then wasteload allocations may be made less stringent. Thus, the TMDL process provides for nonpoint source control tradeoffs." The States may trade between point sources and nonpoint sources identified in this TMDL as long as three general conditions are met; 1) the total allowable load to the waterbody is not exceeded, 2) the trading of loads from one source to another continues to properly implement the applicable water quality standards and embraces the assumptions and methodology of these TMDLs, and 3) the trading results in enforceable controls for each source. Final control plans and loads should be identified in publicly available planning document, such as the State's water quality management plan (see 40 CFR 130.6 and 130.7(d)(2). These final plans must be consistent with the goals of the approved TMDLs. While the nature and considerations of the Step 1 low-flow TMDL make trading between point and nonpoint sources unavailable, EPA expects that this option will be available when the Step 2 high-flow TMDL is developed.

3) The TMDLs consider the impacts of background pollutant contributions.

Background pollutant contributions are the result of non-anthropogenic sources such as from stream erosion, wild animal wastes, leaf fall, and other natural or background processes[19]. During low-flow, summer conditions baseflow contributions to the river are considered most influential and are representative of background contributions.

In terms of the low-flow TMDL analysis, EPA used monitoring data from STORET, USGS water-quality data from monitoring stations, baseflow samples collected in 1997 (Senior 1999), and data from a field study conducted by John Davis of Widener University. Furthermore, atmospheric loads from both dry and wet deposition are considered. EPA believes that use of actual in-stream monitoring data and atmospheric data will effectively account for background pollutant contributions.

As previously mentioned, the Christina River Basin drains to the Delaware River Estuary, which is affected by tidal influences. Furthermore, the Christina River, Brandywine Creek, and White Clay Creek also experience similar tidal effects. The tides are the movement of water above and below a datum plane, usually sea level, which causes tidal currents[20]. Tides are the result of the gravitational forces of the sun and moon on the earth.

Of particular importance when considering tidal influences is the net estuarine flow which is the flow that flushes material out of the estuary over some period of time. Estuaries typically have complicated flow patterns from tidal motion impacts resulting in vertical stratification where freshwater inflow rides over saline ocean water. In essence then, any discharge of pollutants to the Delaware River above and below the confluence of the Christina River Basin and the Delaware River, within a certain distance, could potentially impact water quality within the tidally influenced portions of the basin.

The tidal estuary portion of the EFDC model is used to characterize the Delaware River Estuary and consider potential impacts to water quality within the Christina River basin from pollutant loads to the estuary. There are 23 point sources discharging to the Delaware River which were considered in the linkage analysis. In considering which discharges to include, the spatial range was limited to about 10 miles above and below the confluence of the Christina River and the Delaware River due to the tidal excursion which is approximately 8 miles.

It is important to recognize that these pollutant loads are discharged outside the basin, however, increased pollutant loads from these sources could negatively impact the water quality within the tidally influenced segments of the basin causing violations of water quality standards. Therefore, EPA is

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[19] Supra, footnote 4. Pg 5-5.

[20] Supra, footnote 5. Section 3.

including the point source loads for those dischargers on the Delaware River in table 28 above and EPA considers them as background conditions for the estuary. While explicit analyses to determine the exact nature and magnitude of impacts to water quality in the tidal portions of the Christina River Basin from increased or decreased pollutant loads from the Delaware Estuary has not been performed, any changes to pollutant loads from these sources should strive to be consistent with the existing pollutant loads in the estuary.

4) The TMDLs consider critical environmental conditions.

Federal regulations at 40 CFR 130.7(c)(1) require TMDLs to take into account critical conditions for streamflow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of all waterbodies of the Christina River Basin are protected during times when it most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken to meet water quality standards.[21] Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence. In specifying critical conditions in the waterbody, an attempt is made to use a reasonable "worst-case" scenario condition. For example, stream analysis often uses a low-flow (7Q10) design condition as critical because the ability of the waterbody to assimilate pollutants without exhibiting adverse impacts is at a minimum. Additionally, the *Technical Support Document for Water Quality-based Toxics Control (EPA 505-2-90-001)* recommends the 1Q10 flow (minimum 1-day flow expected to occur every 10 years) or 7Q10 (minimum 7-day flow expected to occur every 10 years) as the critical design periods when performing water quality modeling analysis. Historically, these so-called "design" flows were selected for the purposes of waste load allocation analyses that focused on instream dissolved oxygen concentrations and protection of aquatic life[22]. Pennsylvania, Delaware, and Maryland specify 7Q10 as the design or critical conditions for the application of water quality criteria in their Water Quality Standards.

The Christina River basin TMDL adequately addresses critical conditions for flow through the use of 7Q10 flows during the model period from August 1 to August 31. The 7Q10 values are based on data from 17 USGS stream gages in the Christina Basin. Table 29 below presents flow statistics from USGS gages in the basin.

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[21] EPA Memorandum regarding EPA Actions to Support High Quality TMDLs from Robert H. Wayland III, Director, Office of Wetlands, Oceans, and Watersheds to the Regional Water Management Division Directors, August 9, 1999.

[22] Supra, footnote 17. Section 5.2.

Table 29, Summary of flow statistics from USGS gages in the Christina River Basin

USGS Gage ID	Drainage Area (mi^2)	Years of Record	Average Flow	Harmonic Mean	7Q10 Flow	1Q10 Flow	7Q1 Flow	1Q1 Flow
01478000	20.5	1944-94	28.21	8.31	1.53	0.54	3.79	1.83
01478500	66.7	1952-79	85.91	47.10	11.00	10.15	24.05	22.38
01478650		1994		38.66				
01479000	89.1	1932-94	114.65	62.19	15.60	14.04	31.23	28.45
01479820		1989-96		24.69				
01480000	47.0	1944-94	63.39	36.51	10.25	8.91	18.38	16.37
01480015		1990-94		41.08				
01480300	18.7	1961-96	26.25	12.83	3.40	3.01	6.62	6.19
01480500	45.8	1944-96	66.33	34.64	8.24	7.34	15.41	14.21
01480617	55.0	1970-96	91.31	52.79	19.02	15.54	24.84	21.63
01480650	6.2	1967-68	6.00	3.51				
01480665	33.4	1967-68	36.36	23.45				
01480700	60.6	1966-96	93.46	50.53	13.86	12.17	21.84	19.87
01480800	81.6	1959-68	86.63	44.81	12.56	11.86	20.57	18.81
01480870	89.9	1972-96	153.43	87.17	28.44	23.62	37.66	34.63
01481000	287.0	1912-96	395.13	234.13	70.63	65.04	117.01	107.14
01481500	314.0	1947-94	477.01	266.73	78.13	71.96	123.45	113.32

In terms of pollutant loading, the critical conditions for point source loads occur during times when maximum flow and concentrations are being discharged. The maximum flows and loads are based on the NPDES permits for each facility. These conditions for point sources are used in the critical condition analysis and allocation scenarios.

Nonpoint source loads were based on monitoring data from STORET as well as data collected by USGS, baseflow samples collected in 1997 and data collected by PA DEP and DE DNREC and are representative of background contributions as well as expected land-based, nonpoint sources during low-flow conditions. During these conditions, land-based nonpoint sources are expected to contribute very little pollutant loadings to the waterbody. Furthermore, the ability of the waterbody to assimilate pollutant loads during these low-flow conditions is at a minimum. Consideration of nonpoint source loads would simply remove assimilative capacity and cause further reductions to point sources in order to achieve water quality standards. As can be seen from Table 8, in most watersheds point sources are the dominant contributors of pollutant loadings. The data sets were used to develop characteristic loads of parameters of concern (carbon, nitrogen, phosphorus, DO, algae) for each of the 39 subwatersheds as delineated by the HSPF model. Use of these loads in the model provides the ability to integrate past pollutant loading events. It is recognized that delayed impacts on dissolved oxygen levels from wet-weather events during critical summertime periods may occur. However, Thomann and Mueller (1987) observed that "for some rivers and estuaries, the deposition of solids proceeds only during the low flow summer and fall months when velocities are low. High spring flows the following year may scour the bottom clean and reduce the problem until velocities decrease again. Intermediate cases are common where high flows may scour only a portion of the deposit, oxidize a portion, and then redeposit the material in another location."[23] It is likely that the use of site-specific data to characterize nonpoint source loads during critical conditions would consider those sporadic summertime loading events. In addition, both wet and dry deposition of atmospheric loads are included in the model.

The water quality parameters of concern are DO and nutrients throughout the system. However, as previously discussed, DO can be affected by BOD, SOD, algae, and reaeration. These parameters, in addition to nitrogen and phosphorus, are addressed within the linkage analysis to ensure that the pollutant allocation scenario will ensure that water quality standards are met and maintained throughout the system.

5) The TMDLs consider seasonal environmental variations.

Addressing seasonal variation, similar to critical conditions, is necessary to ensure that water quality standards are met during all seasons of the year. Seasonal variations involve changes in streamflow as a result of hydrologic and climatological patterns. In the continental United States, seasonally high flow normally occurs during the colder period of winter and in early spring from snowmelt and spring rain, while seasonally low flow typically occurs during the warmer summer and early fall drought periods[24]. Other seasonal variations include reduced assimilative capacity from changes in flow and temperature as well as sensitive periods for aquatic biota. Seasonal fluctuations in both point and nonpoint source loads must also be considered.

In terms of the point source loads, the values used in the model are representative of those loads expected during the summer season based on DMRs, NPDES permit limits, or characteristic concentrations. Likewise, the use of data from STORET, USGS, and baseflow sampling to characterize expected nonpoint source loads during the summer will effectively consider seasonality.

EPA expects that seasonal variations will continue to be addressed through the development of

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[23] Supra, footnote 5, Section 6.3.4.

[24] Supra, footnote 8. Section 2.3.3.

the HSPF model. Once this model is linked with EFDC, this will provide EPA with a powerful tool to investigate seasonality, critical conditions, and alternate allocation strategies on a larger temporal and spatial scale. However, use of the EFDC model to represent critical low-flow summer conditions prior to development of the HSPF model in no way downgrades the scientific validity or defensibility of the current TMDL analysis and allocation scenario. Regardless, use of the fully integrated and linked model would still require consideration of critical conditions and seasonality. It is reasonable to expect that the allocation scenario from this integrated analysis would reflect the same critical condition and seasonality components in the current low-flow analysis and result in similar pollutant loading allocations.

6) The TMDLs include a margin of safety.

This requirement is intended to add a level of safety to the modeling process to account for any uncertainty or lack of knowledge. Margins of safety may be implicit, built into the modeling process, or explicit, taken as a percentage of the wasteload allocation, load allocation, or TMDL.

In consideration of the sheer quality and quantity of data and the development of the HSPF watershed loading model which will be linked to this EFDC model, EPA is utilizing an implicit margin of safety through the use of conservative assumptions within the model application. An example of a conservative assumption used in this model is the discharge of point sources located on tributaries directly into the model without consideration of attenuation in the tributary water. The effect is conservative in terms of the mainstem river segment since modeling directly to the mainstem will not consider potential attenuation between the point of discharge into the tributary and confluence with the downstream mainstem segment. This could potentially affect the pollutant allocation scenario. The exact nature of the effect is not known and could be positive or negative. The reverse, however, is not conservative when considering the tributary since negative water quality impacts could be occurring. The ability to model these water quality effects is extremely limited due to lack of resources, time, and data and use of this conservative assumption is valid.

It should be pointed out that this modeling effort relies on data which could be easily characterized as extensive and high-quality . The number of USGS stations and water quality stations, period of record, multiple sources of data, site-specific studies, and comprehensive review and analysis of the model application and techniques all contribute to the confidence EPA has in this TMDL analysis.

7) The TMDLs have been subject to public participation.

Public participation is a requirement of the TMDL process and is vital to it’s success. At a minimum, the public must be allowed at least 30 days to review and comment on a TMDL prior to establishing the TMDL. In addition, EPA must provide a summary of all public comments and our response to those comments to indicate how the comments were considered in the final decision.

For several years, the Christina Basin Water Quality Management Committee and Policy Committee have served as valuable forums to discuss Christina issues including the low-flow TMDL study. During the past two years as the work on the TMDL has accelerated and reached completion, updates on the status of the TMDL have been presented at the following meetings. These meetings, while not explicitly announced to the general public, were open to the public and specific individuals were notified via email.

Christina Basin Water Quality Management Committee Meetings:
- March 12, 1999
- April 22, 1999
- August 5, 1999
- January 28, 2000
- March 30, 2000.

Christina River Basin Policy Committee Meetings:
- October 29, 1999
- May 31, 2000.

In addition to the above meetings, a public outreach task force of the Christina Basin Water Quality Management Committee, led by Bob Struble of the Brandywine Valley/Red Clay Creek Valley Association, has held regular meetings to discuss Christina related issues.

Through the efforts of Bob Struble, a special meeting of public outreach task force was held on May 24, 2000. Invitations to the major dischargers in the Christina Basin were distributed for this meeting and representatives from Northwestern Chester Municipal Authority, Downingtown Area Regional Authority, City of Coatesville Authority, Bethlehem Steel Corporation, West Chester/Taylor Run STP and the Cecil County, MD Department of Public Works were in attendance. Also attending were representatives of Delaware and Maryland and engineers representing facilities in the Basin. During this meeting, the modeling results and load allocations from the Christina TMDL model were presented and discussed. The model results and load allocations were discussed at the May 31, 2000 public outreach task force meeting and the May 31, 2000 Policy Committee meeting as well. Additional discharger representatives from Sonoco, Inc. and Kennett Square were present at the May 31 meetings.

The Christina Basin Water Quality Management Committee has published annual reports summarizing activities and ongoing work for the past several years. The Phase III report, which included a summary of the work completed to date on the Christina TMDL and planned future work, was published on August 5, 1999.

A public meeting sponsored by the Delaware Nature Society on the Christina Basin was held at the Ashland Nature Center in Delaware on June 17, 1999. A presentation on the Christina TMDL and related Christina water quality topics was included on the agenda.

<u>Please note–this section is subject to revisions according to the scheduled public meetings and hearings in July and August, as well as the public comment period from August 1 through September 15, 2000.</u>

8) There is reasonable assurance that the TMDLs can be met.

Reasonable assurance indicates a high degree of confidence that each waste load and load allocation in a TMDL will be implemented. EPA expects the States to implement the TMDL by ensuring that NPDES permit limits are consistent with the waste load allocations described herein. According to 40 CFR 122.44(d)(1)(vii)(B), the effluent limitations for an NPDES permit must be consistent with the assumptions and requirements of any available WLA for the discharge prepared by the state and approved by EPA. Furthermore, EPA has authority to object to issuance of an NPDES permit that is inconsistent with WLAs established for that point source. Additionally, according to 40 CFR 130.7(d)(2), approved TMDL loadings shall be incorporated into the States' current Water Quality Management plan. These plans are used to direct implementation and draw upon the water quality assessments to identify priority point and nonpoint water quality problems, consider alternative solutions and recommend control measures. This provides further assurance that the pollutant allocations of the TMDL will be implemented.

In terms of the nonpoint sources, the load allocations are representative of expected pollutant loads during critical conditions from baseflow, atmospheric, and traditional land-based sources. These loadings are not expected to vary significantly. Therefore, reductions from the current load allocations are unnecessary. Reasonable assurance that the current load allocations will be met is based on the extensive data set used to characterize the current nonpoint source pollutant loadings. In addition, the feasibility of control measures necessary to reduce current nonpoint source pollutant loadings is highly questionable.

VIII. References

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